Damage Assessment of NiAl Single Crystal in Grinding Operations

Gregorio R. Murtagian
Advisor: Dr. Steven Danyluk

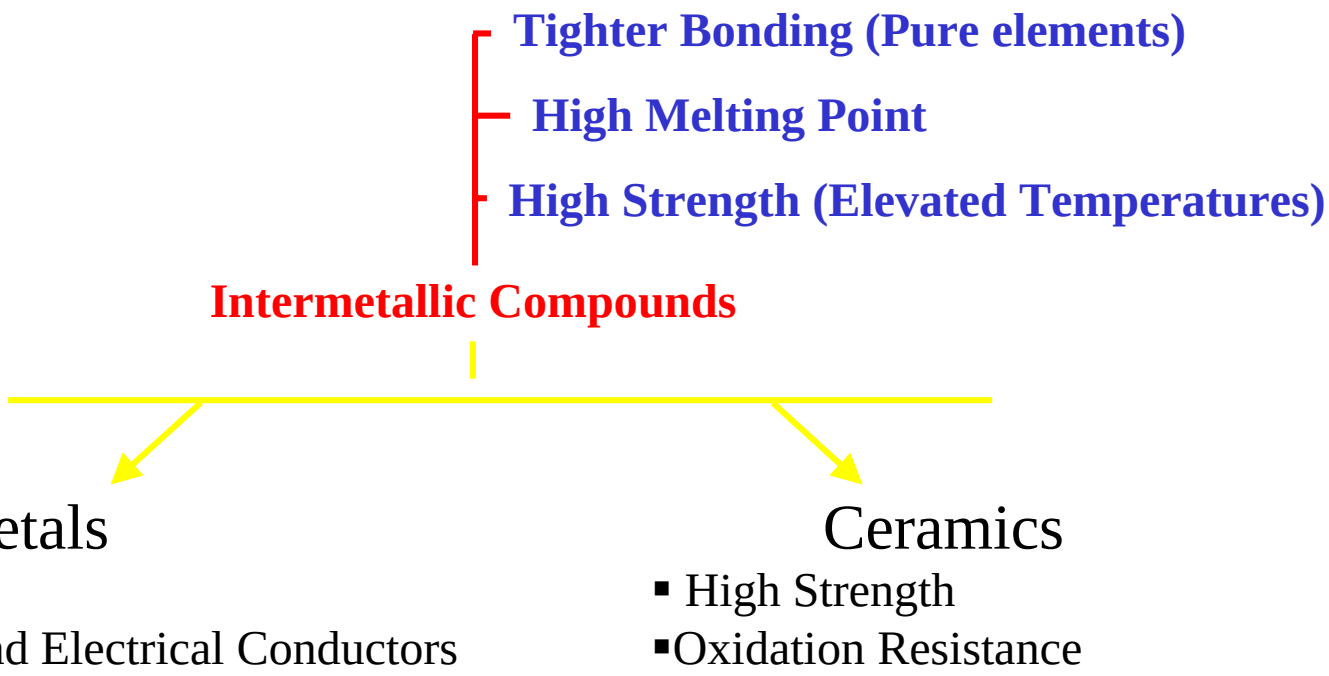
Manufacturing Research Center
GWW School of Mechanical Engineering
Georgia Institute of Technology

Motivation

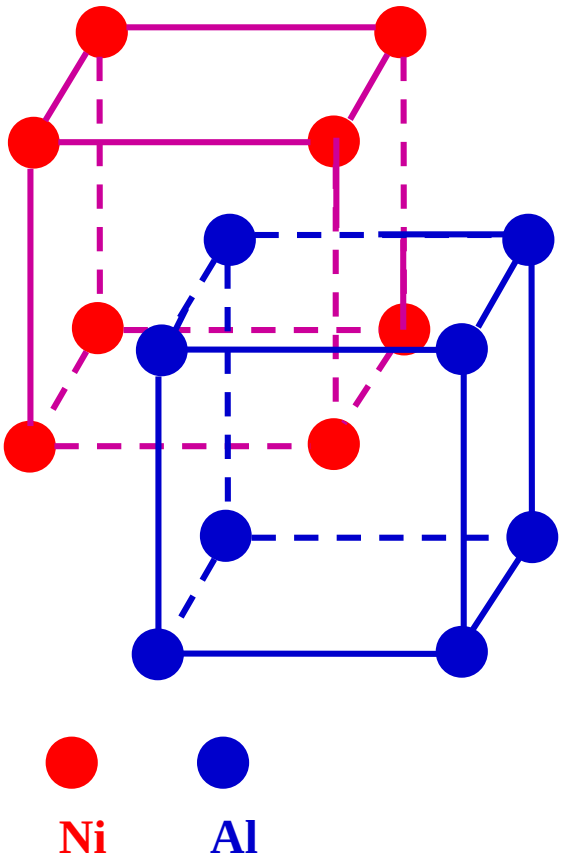
- There is a need in the industry to determine the shaping of intermetallic compounds
- Intermetallic compounds potentially useful for aeronautical industry are TiAl and NiAl (tubine blades)
  - High mechanical strength at elevated temperatures
  - Corrosion resistant
  - **Brittle**
- Grinding is a high throughput process that would be very useful in shaping
- Grinding process generates subsurface damage
  - Cracks
  - Plastic deformation
  - Microestructural changes
  - Residual stresses
- Damage may generate catastrophic failures during element life

IMC Properties

- Intermetallic Compounds
  - Metallic elements (Ni, Al, Ti, Fe,...)
  - Covalent-Ionic-Metallic bonding
  - Specific Crystal Structures
  - Long-range, ordered crystal structure



NiAl Single Crystal



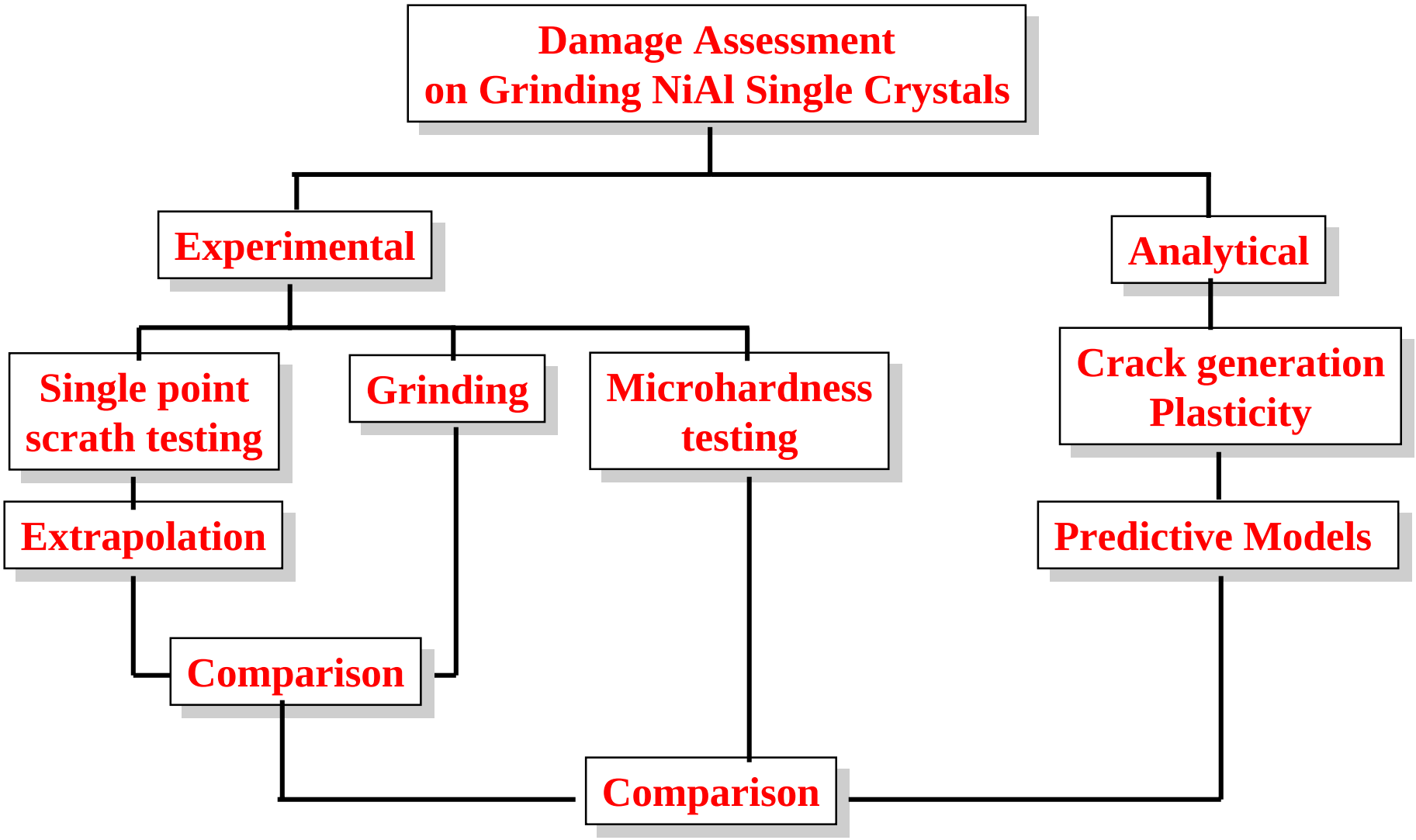
B2 Ordered bcc crystal structure

- Properties
  - Melting Point 1640C - 2985F
  - Density 5.86 g/cm3 (Fe 8 g/cm3)
  - High oxidation resistance
  - High yield strength
- Drawbacks
  - Poor ductility at room temperature
  - Low strength and creep resistance at elevated temperatures (appr. > 600C)
  - Insufficient number of deformation modes

Objective

- Identify the parameters that produce different kinds of damage during grinding on NiAl Single Crystals
  - Specify a process window of grinding variables
  - Identify possible process modifications

Program Overview



Methodology

- Study of damage produced on NiAl Single Crystals by a single point tool on scratch test under different conditions
- Extrapolate results from single point tool to multi-point tool (grinding wheel)

- Input Variables
  - Crystallographic orientation
  - Tool geometry
  - Normal force
  - Scratching speed
- Output Variables
  - Cracking
  - Plastic deformation
  - Temperature increment

Apparatus

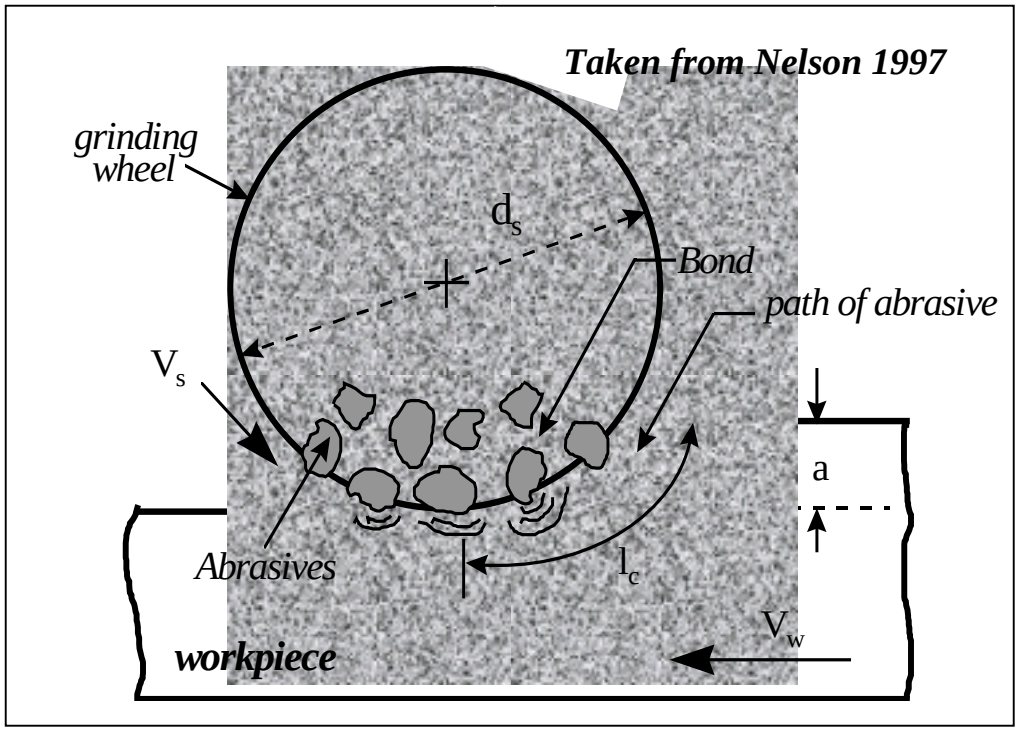
- Specific
  - Scratch Testing machines
    - Load: 1-50N normal load
    - Speed: 0.2mm/sec - 4 m/sec
    - 3 axis dynamometer
    - Data Acqusition cards
  - In situ temperature measurement device
- Grinding Machines
  - PMRC Lab

Previous Research

- **Grinding**
  - **Models**
    - **Undeformed Chip Thickness (Kumar and Shaw, 1981):** $a_g = \left[\frac{\zeta}{\lambda r}\left(\frac{V_w}{V_s}\right)\left(\frac{a}{d_s}\right)\right]^{1/2}$
    - **Force Model (Hahn and Lindsay, 1971):** $Q = \Lambda\left(F_n - F_{th}\right)$
    - **Energy Model (Coes, 1971):** $u = \frac{P_0}{Q} + m$
    - **Temperature Model (Jaeger and Carslaw, 1947):** $\theta_m \approx 1.13\frac{\alpha^{1/2} a^{3/4} v_w^{1/2}}{k d_s^{1/4}}\varepsilon u$
    - **Indentation Model (Nelson, 1997):** $h \approx \left(\frac{\beta^2}{\delta\pi H_v}\right)^{1/2} F_n^{1/2}$
  - **Grinding Intermetallic Compounds (Kumar, 1993; Nelson, 1997)**

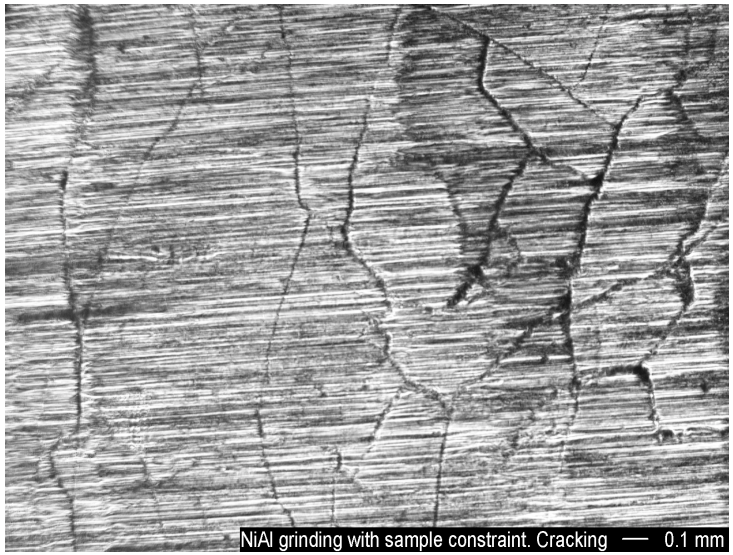
- **Previous Research Inside PMRC**
  - **Control of Grinding Process**
    - **Jenkins (1996)**
    - **Hekman (1997)**
  - **Grinding Intermetallic Compounds**
    - **Nelson (1997)**
    - **Razavi (2000)**

Grinding

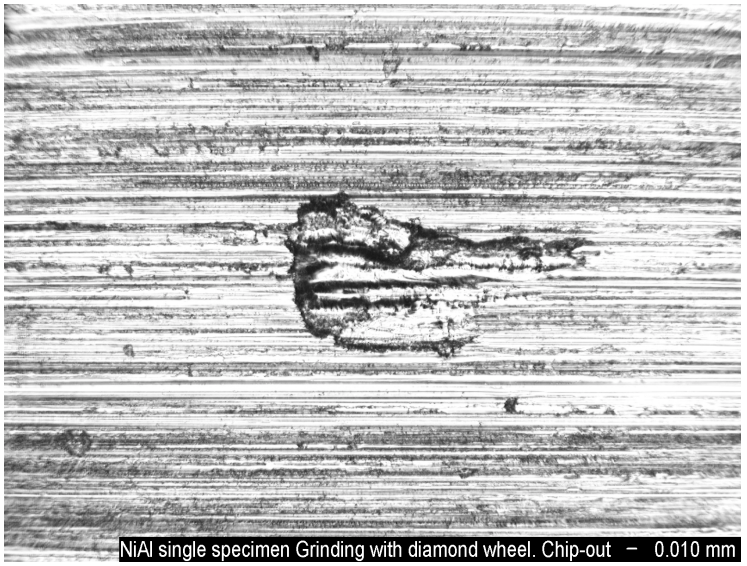


- Grinding variables
  - Material
  - Feed rate (Normal Force)
  - Depth of cut
  - Kind of wheel
    - Grain type
    - Grain size
    - Bond type
  - wheel speed and direction
- Output
  - Surface damage
  - Subsurface damage

Grinding Damage

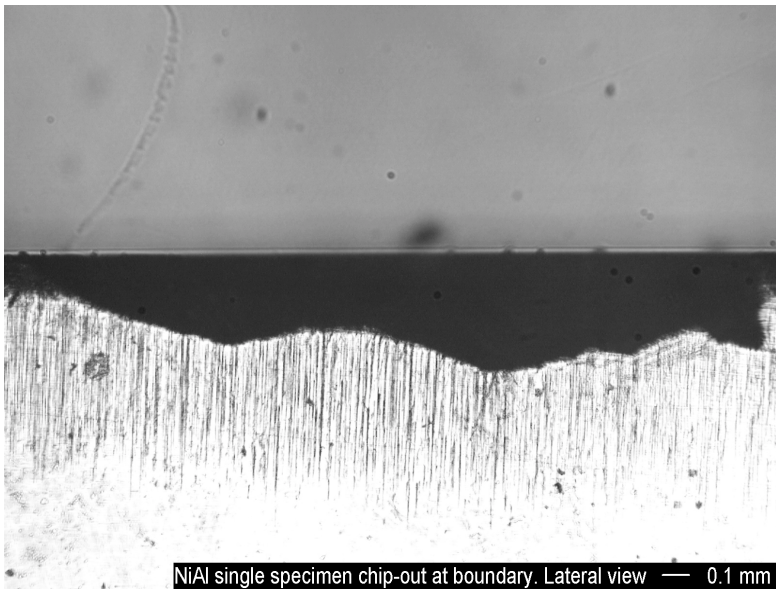


❖Cracking produced by a Al_2O_3 wheel. Top view

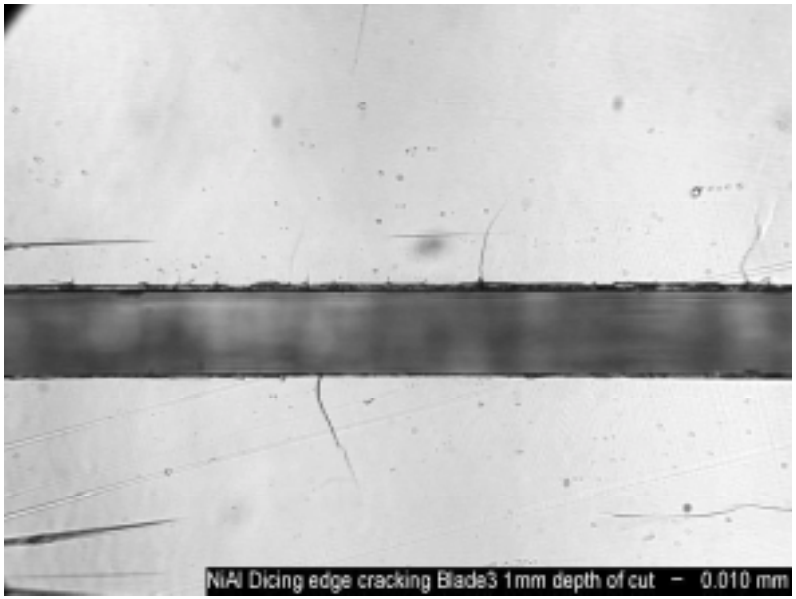


❖Chip-out produced by a diamond wheel. Top view

Damage

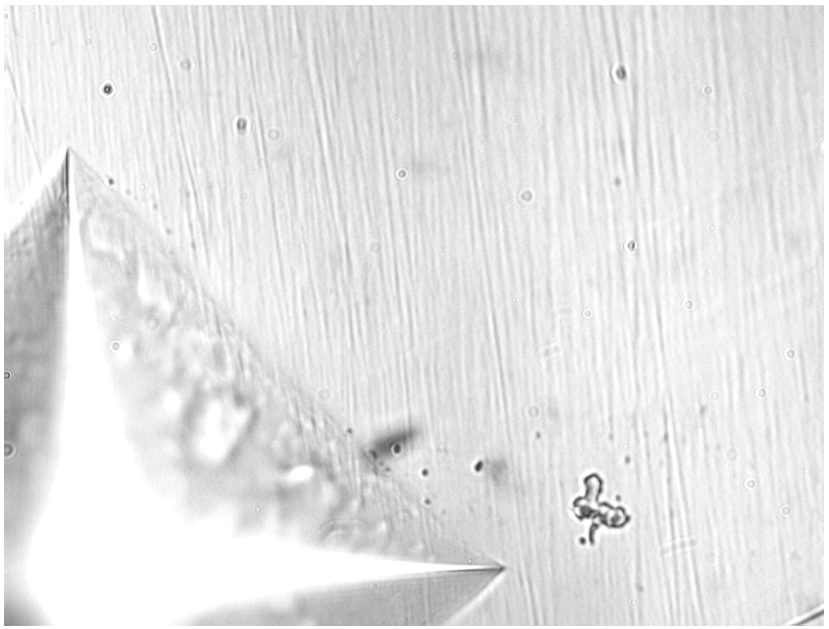


❖Chip-out produced by a diamond wheel. Side view



❖Chip-out and cracking produced by diamond wheel dicing. Top view

Microhardness Test



- Vickers test

Applied Load: 20 N

- Output
  - Large amount of plastic deformation
  - No cracking was observed

The material behavior to cracking damage is strongly dependent on the stress state and strain rate

Summary

- Preliminary work completed
  - Grinding
  - Dicing
  - Indentation

    Cracking is severe

    Depends strongly on stress state and strain rate

- Initiated fabrication of apparatus
  - Single point scratch fixture
  - In situ temperature measurement device completed